Model coupling with the Framework for Aquatic Biogeochemical Models
A demonstration with the European Regional Seas Ecosystem Model

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### Why a framework?

Biogeochemical models are becoming more complex
- Contributions from many individuals/research groups, but final codes remain monolithic and hard to maintain

**Coupling to hydrodynamics is time-consuming and error-prone**
- It requires intimate knowledge of the hydrodynamic model:
  - spatial domain
  - physical variable storage (T,S)
  - numerical schemes
  - input/output

- Each hydrodynamic model requires its own coupling: no standardized Application Programming Interface (API) exists

### Aims

**Distributed development of biogeochemical models**
- Partition functionality over many compact, self-contained modules

**Portability across hydrodynamic models**
- Code biogeochemistry once, use in 0D, 1D, 2D, 3D hydrodynamic models

**Maximum control for end-users**
- Select, couple and configure modules at run-time

### Splitting hydrodynamics and biogeochemistry

**Hydrodynamic model**
- Store physical variables
- Handle advection, diffusion, time integration
- Handle input/output

**Biogeochemical models**
- Provide names & units of variables, parameters, dependencies
- Give a local environment, provide local sink and source terms

### Programming decisions

**Object-oriented Fortran 2003**
- Preprocessor macros for space-dependent constructs

**Enable vectorization**
- API operates on 1D array slices

**Minimize data copying and memory consumption**
- Framework operates directly on arrays in host

**Plain-text configuration of parameterization and coupling**
- Single file based on YAML, http://yam1.org

### Test case: ERSEM

**Statistics**
- Pelagic state variables
- Benthic state variables
- Parameters
- Phytoplankton groups
- Zooplankton groups
- Chemical elements

**FABM-ERSEM: each "integral physical entity" is a module**
- For instance: phosphate, medium-size detritus, diatoms, mesozooplankton

**Coupling at run-time by FABM**
- ERSEM: 24 modules, 400+ coupling links!

### Modularity and coupling

**Performance**

- Original GOTM-BIO/NPZD
- GOTM-FABM
- Bespoke GOTM-ERSEM

- Runtime relative to equivalent GOTM-FABM simulation

### Try it: http://sourceforge.net/projects/fabm/

**Biogeochemical modellers**: Focus on the biogeochemistry. Code it once, then use in many hydrodynamic models.

**Hydrodynamic modellers**: Access ERSEM and other biogeochemical models through documented, efficient interfaces.

Paper forthcoming in Environmental Modelling & Software
Public release of FABM-ERSEM is imminent
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